

J/ ψ and $\psi(2S)$ measurement in $p+p$ collisions at $\sqrt{s} = 200$ and 500 GeV in the STAR experiment

Barbara Trzeciak¹ for the STAR Collaboration

¹Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Brehova 7, 115 19 Praha 1, Czech Republic

E-mail: trzecbar@fjfi.cvut.cz

Abstract. In this paper, results on the J/ ψ cross section and polarization measured via the dielectron decay channel at mid-rapidity in $p + p$ collisions at $\sqrt{s} = 200$ and 500 GeV in the STAR experiment are discussed. The first measurement of $\psi(2S)$ to J/ ψ ratio at $\sqrt{s} = 500$ GeV is also reported.

1. Introduction

J/ ψ and $\psi(2S)$ are bound states of charm (c) and anti-charm (\bar{c}) quarks. Charmonium physical states have to be colorless, however they can be formed via a color-singlet (CS) or color-octet (CO) intermediate $c\bar{c}$ state. One of the first models of the charmonium production, the Color Singlet Model (CSM) [1], assumed that J/ ψ is created through the color-singlet state only. This early prediction failed to describe the measured charmonium cross section which has led to the development of new models. For example, Non-Relativistic QCD (NRQCD) [1] calculations were proposed in which a $c\bar{c}$ color-octet intermediate states, in addition to a color-singlet states, can bind to form charmonia.

However, the charmonium production mechanism in elementary particle collisions is not yet exactly known. For many years measurements of the J/ ψ cross section have been used to test different J/ ψ production models. While many models can describe relatively well the experimental data on the J/ ψ cross section in $p + p$ collisions [2–9], they have different predictions for the J/ ψ polarization. Therefore, measurements of the J/ ψ polarization may allow to discriminate among different models and provide new insight into the J/ ψ production mechanism.

2. Charmonium measurements in STAR

In STAR, charmonia have been measured so far via the dielectron decay channel. The STAR detector [10] is a multi-purpose detector that has large acceptance at mid-rapidity, $|\eta| < 1$ with a full azimuthal coverage. Electrons can be identified using the Time Projection Chamber (TPC) [11] through ionization energy loss (dE/dx) measurement. The Time Of Flight (TOF) detector [12] greatly enhances the electron identification capability at low momenta where the dE/dx bands for electrons and hadrons cross each other. At high p_T , electron identification can be improved by the Barrel Electromagnetic Calorimeter (BEMC) [13] which measures electron energy and shower shape. The BEMC is also used to trigger on high- p_T electrons (HT trigger). Minimum Bias (MB) events are triggered by the Vertex Position Detectors (VPD) [14].

3. J/ψ measurements in $p+p$ at $\sqrt{s} = 200$ GeV

STAR has measured inclusive J/ψ p_T spectra and polarization in $p + p$ collisions at $\sqrt{s} = 200$ GeV via the dielectron decay channel ($B_{ee} = 5.9\%$) at mid-rapidity ($|y| < 1$). These results are compared to different model predictions to understand J/ψ production mechanism in elementary collisions.

Left panel of Fig. 1 shows STAR low and high- p_T measurements of J/ψ p_T spectra [3, 15] compared to model predictions. The Color Evaporation Model (CEM) [16] for prompt J/ψ can describe the p_T spectrum reasonably well, except the region around $p_T \approx 3$ GeV/c where it over-predicts the data. NLO NRQCD calculations with color-singlet and color-octet transitions [17] for prompt J/ψ match the data for $p_T > 4$ GeV/c. NNLO* CS model [18] for direct J/ψ production under-predicts the STAR data, but the prediction does not include contributions from $\psi(2S)$, χ_C and B -meson decays to J/ψ .

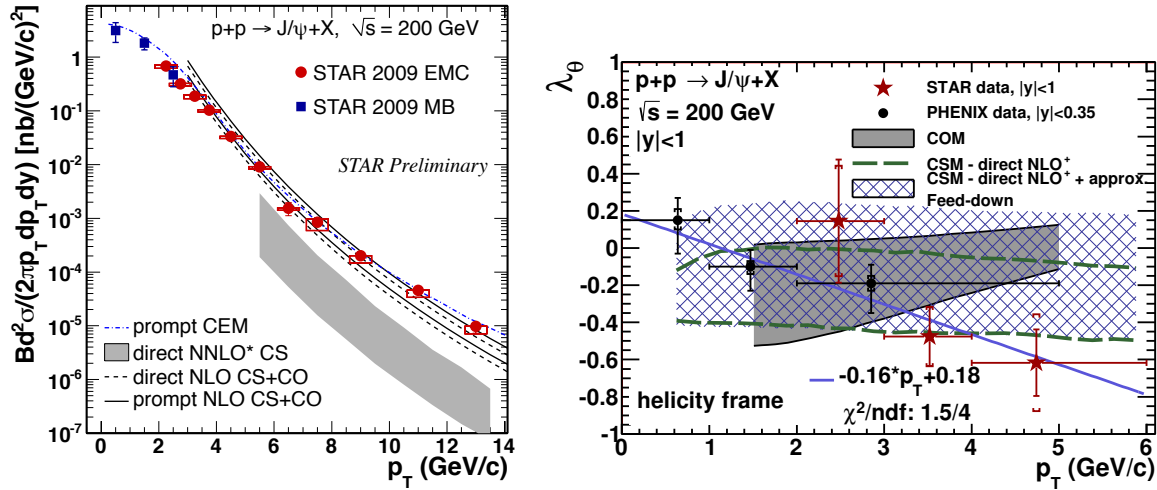


Figure 1. Left: J/ψ invariant cross section vs p_T in $p+p$ collisions at $\sqrt{s} = 200$ GeV at mid-rapidity at low [15] and high p_T [3] shown as blue squares and red circles, respectively, compared to different model predictions [16–18]. Right: Polarization parameter λ_θ vs J/ψ p_T for $|y| < 1$ [19] compared to the PHENIX measurement [20] and two model predictions [21, 22].

In $p+p$ collisions at $\sqrt{s} = 200$ GeV STAR has also measured J/ψ polarization parameter λ_θ in the helicity frame at mid-rapidity and $2 < p_T < 6$ GeV/c [19]. J/ψ polarization is analyzed via the angular distribution of the decay electrons that is described by: $\frac{d^2 N}{d(\cos\theta)d\phi} \propto 1 + \lambda_\theta \cos^2 \theta + \lambda_\phi \sin^2 \theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos \phi$, where θ and ϕ are polar and azimuthal angles, respectively; λ_θ , λ_ϕ and $\lambda_{\theta\phi}$ are the angular decay coefficients. The p_T dependence of λ_θ is shown on the right panel of Fig. 1 with low- p_T PHENIX results [20] and compared to NRQCD calculations [21] and the NLO⁺ CSM prediction [22]. A trend observed in the RHIC data is towards longitudinal polarization as p_T increases and, within experimental and theoretical uncertainties, the result is consistent with the NLO⁺ CSM model.

The inclusive J/ψ production is a combination of prompt and non-prompt J/ψ . The prompt J/ψ production consists of the direct one ($\sim 60\%$) and feed-down from excited states $\psi(2S)$ ($\sim 10\%$) and χ_C ($\sim 30\%$), while non-prompt J/ψ originate from B -hadron decays. STAR has estimated the contribution from B -meson decays using a measurement of azimuthal angular correlation between high- p_T J/ψ and charged hadrons [2, 3]. The relative contribution of B -hadron decays to inclusive J/ψ yield is strongly p_T dependent and it is 10-25% for $4 < p_T < 12$ GeV/c, as it is shown on the left panel of Fig. 2. The measurement is consistent with the FONLL+CEM prediction [23, 24].

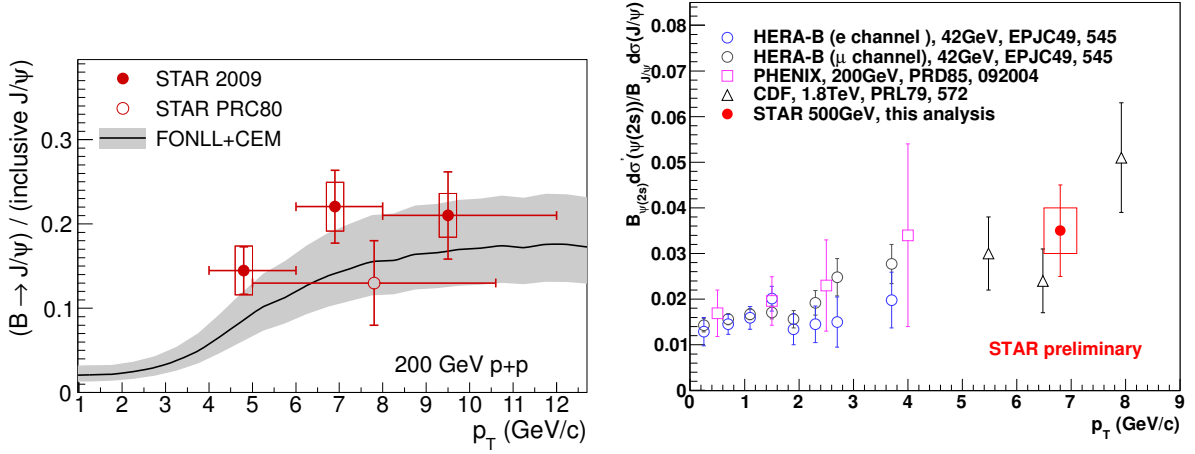


Figure 2. Left: relative contribution from B-meson decays to inclusive J/ψ production in $p+p$ at $\sqrt{s} = 200$ GeV [3] compared to FONLL+CEM calculations [23,24]. Right: ratio of $\psi(2S)$ to J/ψ in $p+p$ collisions at $\sqrt{s} = 500$ GeV from STAR (red circle) compared to results from other experiments at different energies.

4. J/ψ and $\psi(2S)$ measurements in $p+p$ at $\sqrt{s} = 500$ GeV

In order to further test the charmonium production mechanism and constrain the feed-down contribution from the excited states to the inclusive J/ψ production, the J/ψ and $\psi(2S)$ signals were extracted in $p+p$ collisions at $\sqrt{s} = 500$ GeV at mid-rapidity. The J/ψ p_T spectrum is shown on the left panel of Fig. 3. The STAR results at $\sqrt{s} = 500$ GeV (full circles) are compared to those at $\sqrt{s} = 200$ GeV (open circles) and with measurements of other experiments in $p+\bar{p}$ collisions at different energies. The STAR measurements cover p_T range of 4 - 20 GeV/c with a good precision. It was also observed that J/ψ cross section follows the x_T scaling: $\frac{d^2\sigma}{2\pi p_T dp_T dy} = g(x_T)/(\sqrt{s})^n$, where $x_T = 2p_T/\sqrt{s}$, with $n = 5.6 \pm 0.2$ at mid-rapidity and $p_T > 5$ GeV/c for a wide range of colliding energies [2]. At $\sqrt{s} = 500$ GeV the same x_T scaling of high- p_T J/ψ production is seen, as shown on the right panel of Fig. 3.

Right panel of Fig. 2 shows $\psi(2S)/J/\psi$ ratio from STAR (red full circle) compared to measurements of other experiments at different colliding energies, in $p+p$ and $p+A$ collisions. The STAR data point is consistent with the observed trend, and no collision energy dependence of the $\psi(2S)$ to J/ψ ratio is seen with the current precision.

The statistics available at $\sqrt{s} = 500$ GeV will allow us to extract the frame invariant polarization parameter, also in different reference frames, providing model independent information about the J/ψ polarization [25]. It will be possible to measure the azimuthal polarization parameter, λ_ϕ , and improve precision of the λ_θ measurement. Analysis of J/ψ polarization at $\sqrt{s} = 500$ GeV is ongoing.

5. Summary

In summary, STAR has measured the inclusive J/ψ cross section and polarization in $p+p$ collisions at $\sqrt{s} = 200$ GeV as a function of p_T . The measurements are compared to different model predictions of the J/ψ production. The p_T spectrum is described well by the NRQCD calculations while the measured polarization parameter λ_θ is consistent with the NLO⁺ CSM prediction. STAR new result for J/ψ at $\sqrt{s} = 500$ GeV extends p_T reach up to 20 GeV/c. The first measurement of $\psi(2S)/J/\psi$ ratio in $p+p$ collisions at $\sqrt{s} = 500$ GeV is reported and compared with results from other experiments. No collision energy dependence is observed.

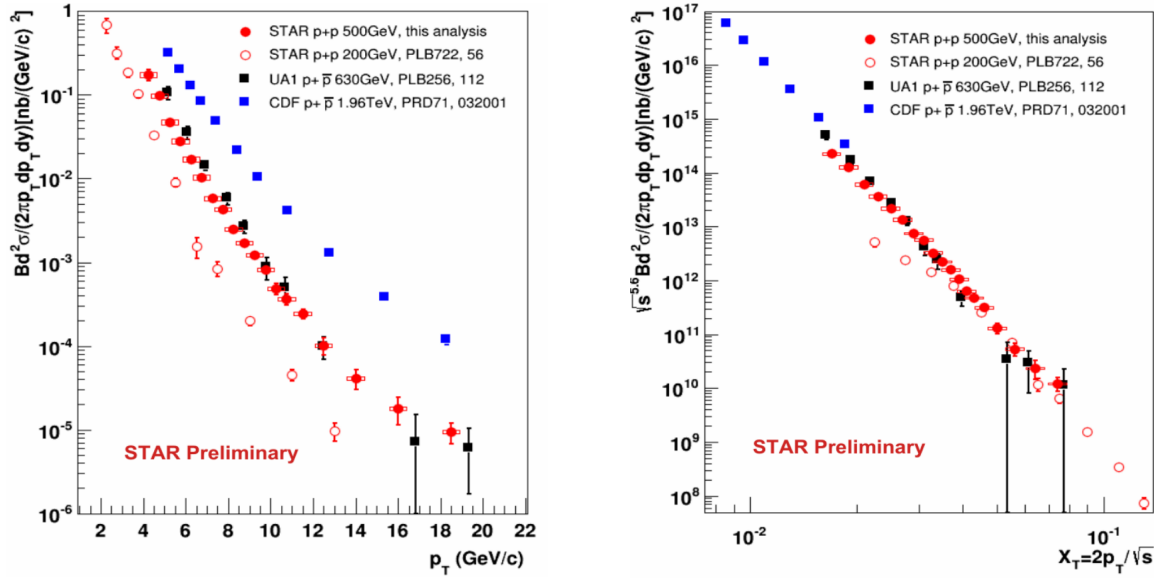


Figure 3. J/ψ invariant cross section vs p_T , left panel, and invariant cross section multiplied by $\sqrt{s}^{5.6}$ vs x_T , right panel, in $p+p$ collisions at $\sqrt{s} = 500$ GeV at mid-rapidity shown as full circles compared to measurements at different energies.

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References

- [1] Braaten E, Fleming S and Yuan T C 1996 *Ann. Rev. Nucl. Part. Sci.* **46** 197–235 (*Preprint hep-ph/9602374*)
- [2] Abelev B *et al.* (STAR Collaboration) 2009 *Phys. Rev. C* **80** 041902 (*Preprint 0904.0439*)
- [3] Adamczyk L *et al.* (STAR Collaboration) 2013 *Phys. Lett. B* **722** 55–62 (*Preprint 1208.2736*)
- [4] Adare A *et al.* (PHENIX Collaboration) 2012 *Phys. Rev. D* **85** 092004 (*Preprint 1105.1966*)
- [5] Abe F *et al.* (CDF Collaboration) 1997 *Phys. Rev. Lett.* **79**(4) 572–577
- [6] Acosta D *et al.* (CDF Collaboration) 2005 *Phys. Rev. D* **71** 032001 (*Preprint hep-ex/0412071*)
- [7] Aad G *et al.* (ATLAS Collaboration) 2011 *Nucl. Phys. B* **850** 387–444 (*Preprint 1104.3038*)
- [8] Khachatryan V *et al.* (CMS Collaboration) 2011 *Eur. Phys. J. C* **71** 1575 (*Preprint 1011.4193*)
- [9] Aaij R *et al.* (LHCb Collaboration) 2011 *Eur. Phys. J. C* **71** 1645 (*Preprint 1103.0423*)
- [10] Ackermann K *et al.* (STAR Collaboration) 2003 *Nucl. Instrum. Meth. A* **499** 624–632
- [11] Anderson M *et al.* 2003 *Nucl. Instrum. Meth. A* **499** 659–678 (*Preprint nucl-ex/0301015*)
- [12] Llope W J *et al.* 2012 *Nucl. Instrum. Meth. A* **661** 110–113
- [13] Beddo M *et al.* (STAR Collaboration) 2003 *Nucl. Instrum. Meth. A* **499** 725–739
- [14] Llope W J *et al.* 2004 *Nucl. Instrum. Meth. A* **522** 252–273 (*Preprint nucl-ex/0308022*)
- [15] Kosarzewski L (STAR Collaboration) 2012 *Acta Phys. Polon. Supp.* **5** 543–548
- [16] Frawley A D, Ullrich T and Vogt R 2008 *Phys. Rept.* **462** 125–175 (*Preprint 0806.1013*)
- [17] Ma Y Q, Wang K and Chao K T 2011 *Phys. Rev. D* **84** 114001 (*Preprint 1012.1030*)
- [18] Artoisenet P *et al.* 2008 *Phys. Rev. Lett.* **101** 152001 (*Preprint 0806.3282*)
- [19] Adamczyk L *et al.* (STAR Collaboration) 2013 *Phys. Lett. B* **739** 180 (*Preprint 1311.1621*)
- [20] Adare A *et al.* (PHENIX Collaboration) 2010 *Phys. Rev. D* **82**(1) 012001
- [21] Chung H S, Yu C, Kim S and Lee J 2010 *Phys. Rev. D* **81**(1) 014020
- [22] Lansberg J 2011 *Phys. Lett. B* **695** 149–156 (*Preprint 1003.4319*)
- [23] Bedjidian M, Blaschke D, Bodwin G T, Carrer N, Cole B *et al.* 2004 (*Preprint hep-ph/0311048*)
- [24] Cacciari M, Nason P and Vogt R 2005 *Phys. Rev. Lett.* **95** 122001 (*Preprint hep-ph/0502203*)
- [25] Faccioli P, Lourenco C, Seixas J and Wohri H K 2010 *Eur. Phys. J. C* **69** 657–673 (*Preprint 1006.2738*)